# Biomimicry, Innovation, Inspiration, and Challenges

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Ali Dhinojwala[3]

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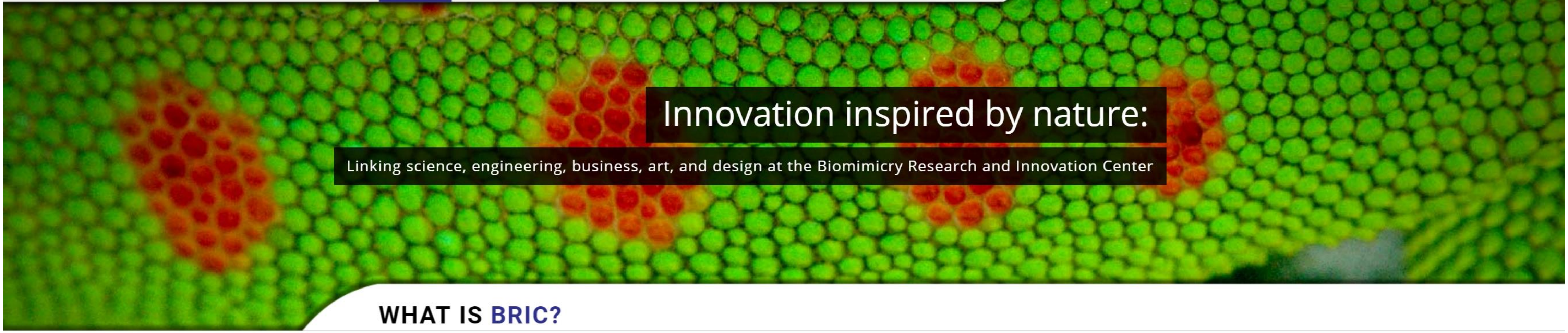
# Outline

- Biomimicry Research and Innovation Center
- Gecko Adhesion
- Biomimicry, Innovation, Inspiration and Challenges




## WHAT IS BRIC?

The University of Akron Biomimicry Research and Innovation Center (**BRIC**) is a center dedicated to the advancement of innovation inspired by nature. Together with our regional partners, we are building an internationally recognized center for biomimicry research, design, teaching and training.

The work of BRIC is to align the creative ideas of scientists, engineers, artists, and entrepreneurs to catalyze invention. By partnering our existing biomimetic research expertise with the Great Lakes Biomimicry (GLBio) business leaders, the BRIC paradigm lays the foundation for sustainable economic and educational innovation powered by nature-inspired technologies.

### IN PARTNERSHIP WITH:

The University of Akron

BIOMIMICRY 3.8

GREAT LAKES BIOMIMICRY








## CURRENT BIOMIMICRY FELLOWS

**REBECCA EAGLE-MALONE**

*The Cleveland Zoological Society, Cleveland Metroparks Zoo*

**FOCUS:** Saving the World! Finding solutions to problems we've created, via biomimicry and bioremediation.

Read Bio

**SEBASTIAN ENGELHARDT**

*Ross Environmental Services Inc.*

**FOCUS:** Sustainable solution for scrubber water stream ensuring 4 million + gallons of water remain in the ecosystem.

Read Bio

**DAPHNE FECHEYR-LIPPENS**

*Parker Hannifin*

**FOCUS:** Understanding the mechanism by which Ultraviolet (UV) light can be reflected by biological materials, e.g. white-colored avian eggshells, and how this knowledge might be applied to create protective systems to harmful solar radiation.

Read Bio

**EMILY KENNEDY**

*GOJO Industries, Inc.*

**FOCUS:** Generating and testing theory about biomimetic innovation in a business environment to create part of a procedural template that boosts outcome value.

Read Bio

**BANAFSHEH KHAKIPOOR**

*Avon Lake Regional Waters, and Teaching Institute for Excellence in STEM (TIES)*

**FOCUS:** Study of lake's ecology, specifically cyanotoxins, by developing a network of sensors inspired from nature.

Read Bio

**DANIEL MAKSUTA**

*Kimberly-Clark*

**FOCUS:**Integrating nature's solutions into our own: from products to methodologies.

Read Bio

**KELLY SIMAN**

*The Nord Family Foundation, Lake Ridge Academy*

**FOCUS:** Using biomimicry as a sustainability mechanism to assist communities in climate change adaptation and mitigation techniques.

Read Bio

**LAMALANI SIVERTS**

*Avon Lake Regional Water and The Teaching Institute for Excellence in STEM education (TIES)*

**FOCUS:** Integrating biomimicry into STEM education curriculum and solutions for detecting harmful algal blooms in drinking source water.

Read Bio

**MICHAEL WILSON**

*Lubrizol*

**FOCUS:** Understanding the interactions of biological systems at surfaces and interfaces to perform specific functions.

Read Bio

**SARAH HAN**

*The Goodyear Tire & Rubber Company*

**FOCUS:** Developing and optimizing the combination of aesthetic form and practical function in various systems through biomimetic practice.

Read Bio

**STEPHEN HOWE**

*Bendix Commercial Vehicle Systems*

**FOCUS:** Developing strategies for integrating biomimicry into existing innovation frameworks of companies. Understanding and applying natural strategies of moving through fluids, e.g. birds, fish, whales, etc.

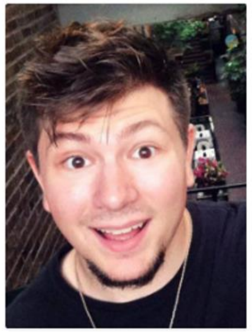
Read Bio

**BOR-KAI HSIUNG**

*Sherwin-Williams*

**FOCUS:** Mechanisms behind spider silks formation and how they affect the properties of silks. Also, structural colors on spiders.

Read Bio



**DEREK MILLER**

*MC2 STEM High School*

**FOCUS:**To merge the arts and sciences through biomimicry, and create architectural and interactive designs through interfaces between digital and physical environments.

Read Bio

**ADAM J. PIERCE**

*Great Lakes Biomimicry (GLBio), National Inventors Hall of Fame STEM School*

**FOCUS:** Using biomimicry as a tool for organic architecture and urban design.

Read Bio

**ARIANA RUPP**

*Nottingham Spirk, Fulbright program*

**FOCUS:**Using biomimicry for product development within biomedical engineering and packaging design.

Read Bio

# Biomimicry Innovation Ecosystem

R&D OD

Biomimicry Startups

Biomimetic Products and Services

Corporate Funding

Companies Using Biomimicry

Biomimicry PhD Fellows

K12 Teacher Biomimicry Training

K12 Biomimicry Curriculum

Biomimicry Skills and Passion

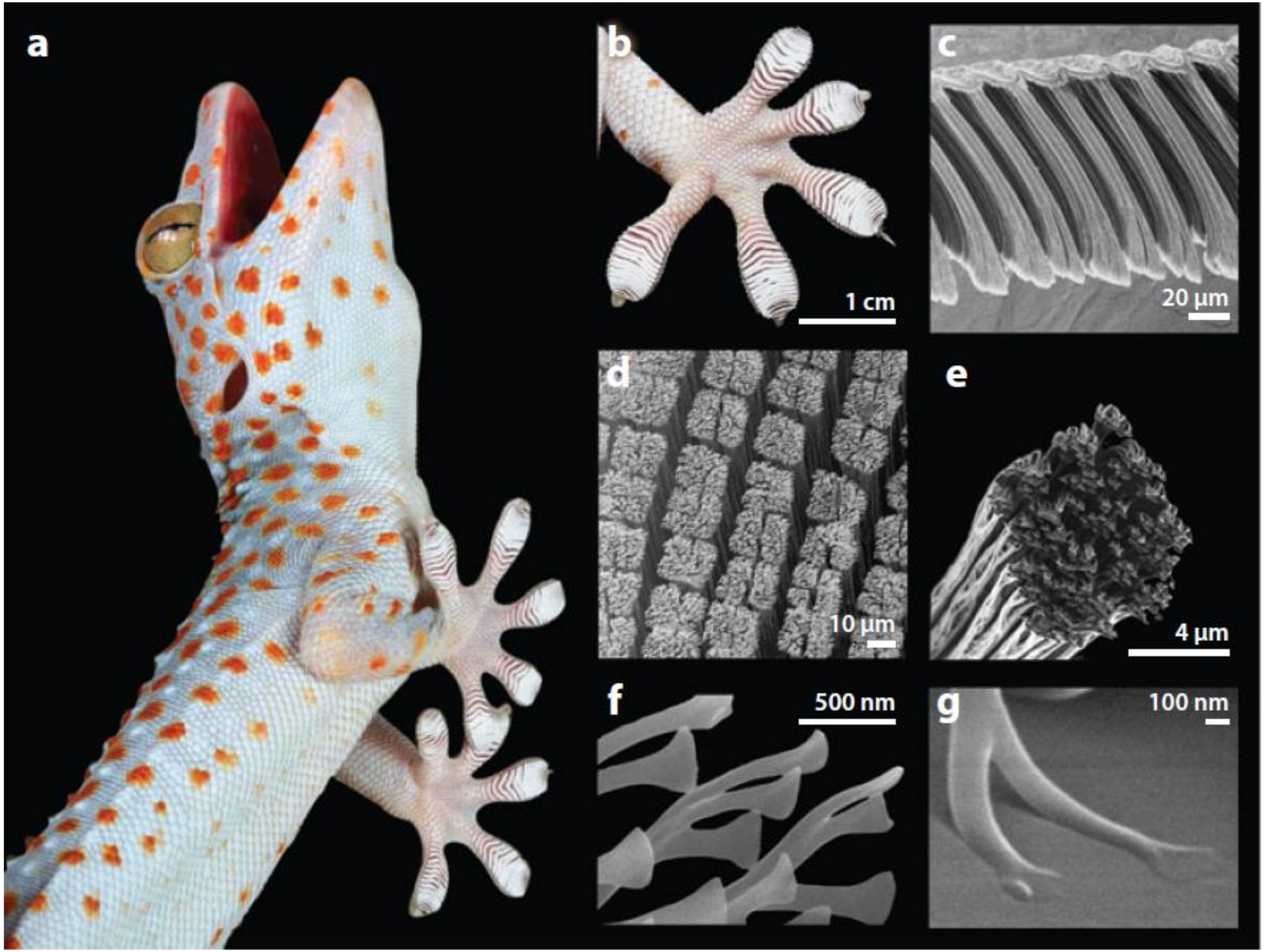
Foundation Funding

K12

GREAT LAKES BIOMIMICRY

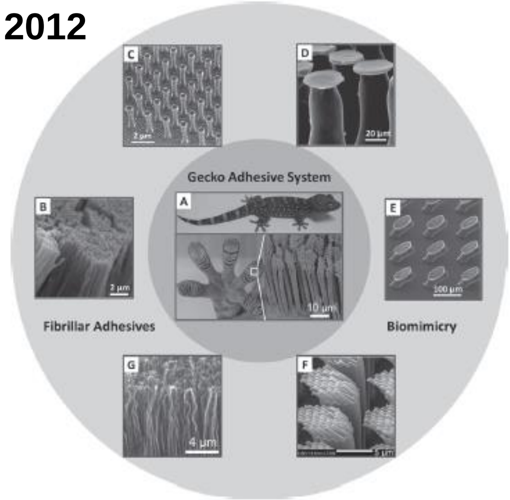
BIOMIMICRY RESEARCH INNOVATION CENTER

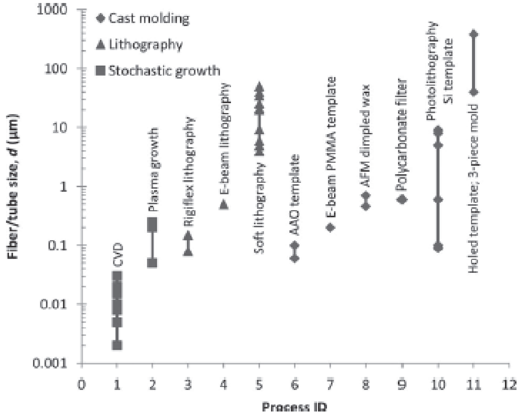
# Gecko-Inspired Adhesion

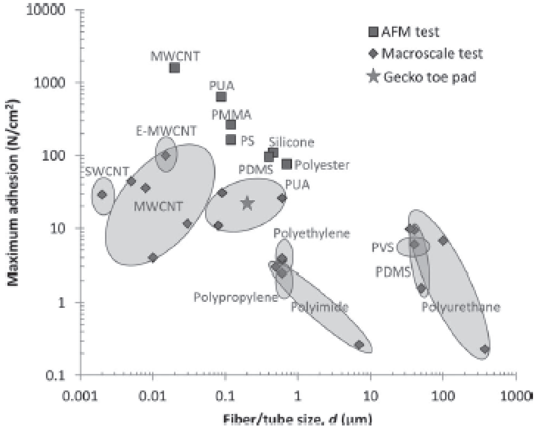



**Autumn et al. 2014**

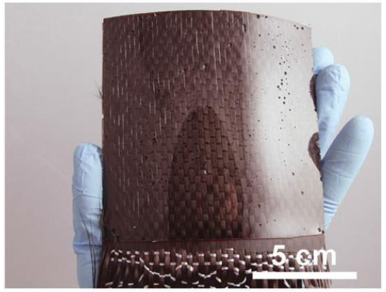
**Hu and Xia 2012**

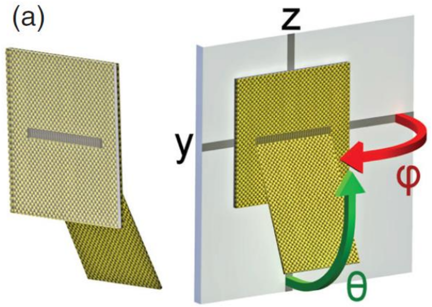


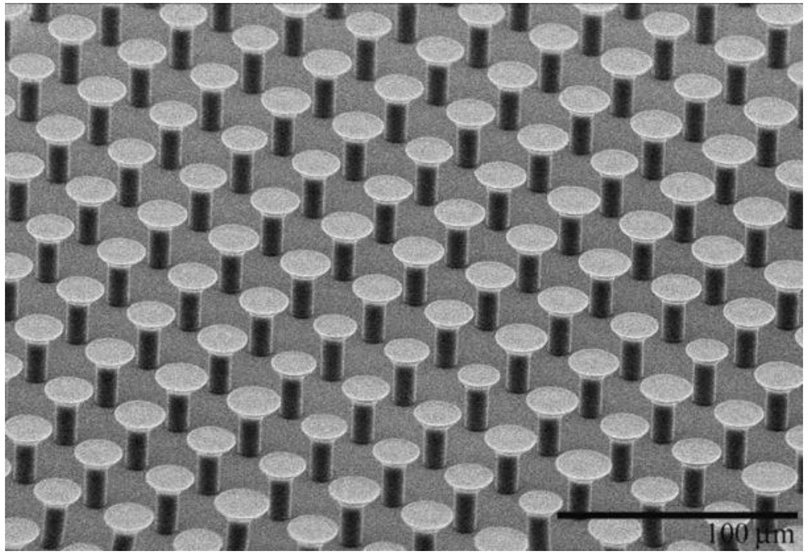



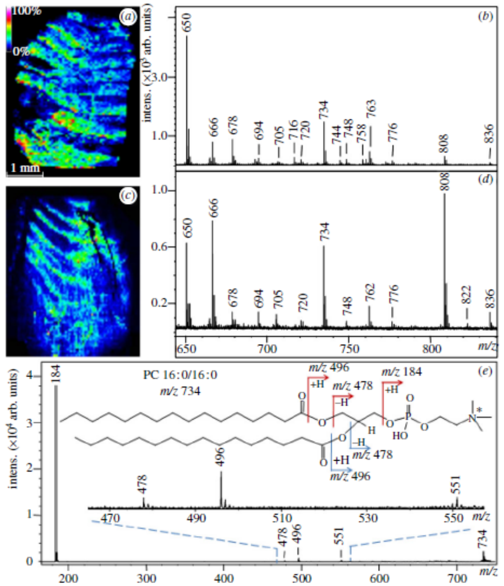

**Bartlett et al. 2012: GeckSkin**

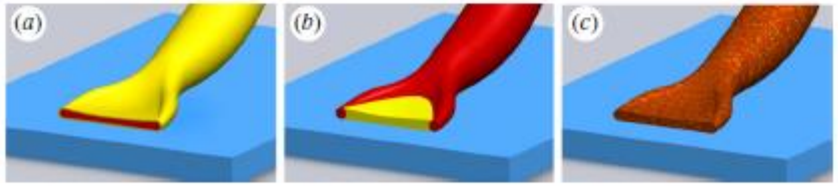



**Aksak et al. 2014: Nanogriptech**

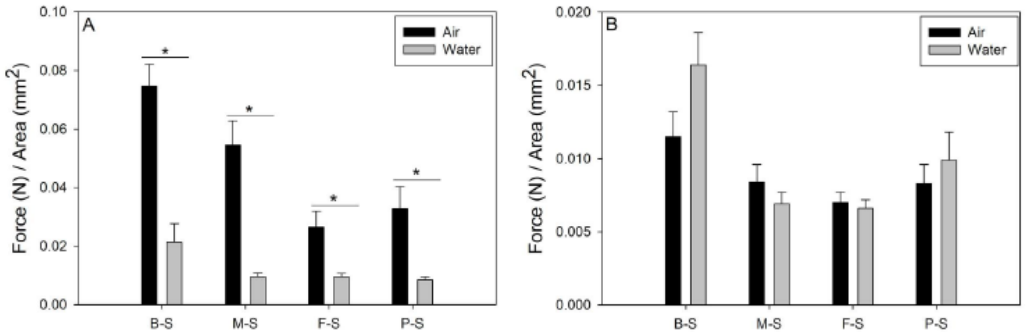




Hsu et al. 2011

**Self-cleaning; anti-matting**

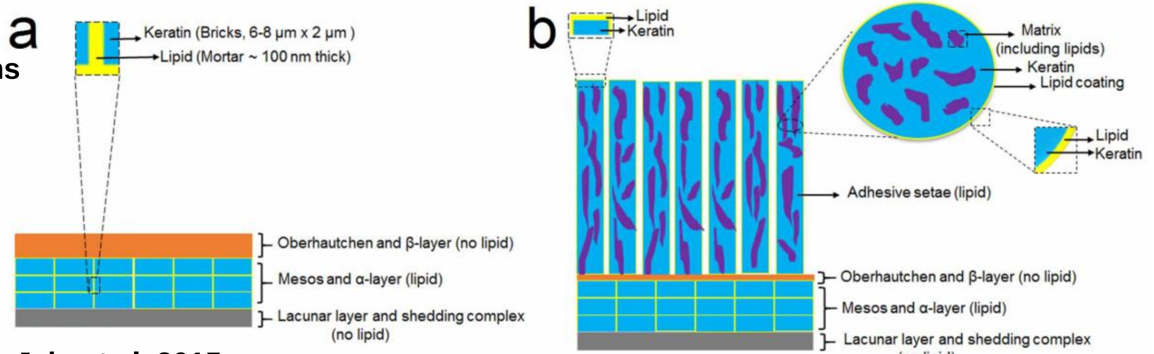

Hu et al. 2012

**Hydrophobic; resistant to wetting**



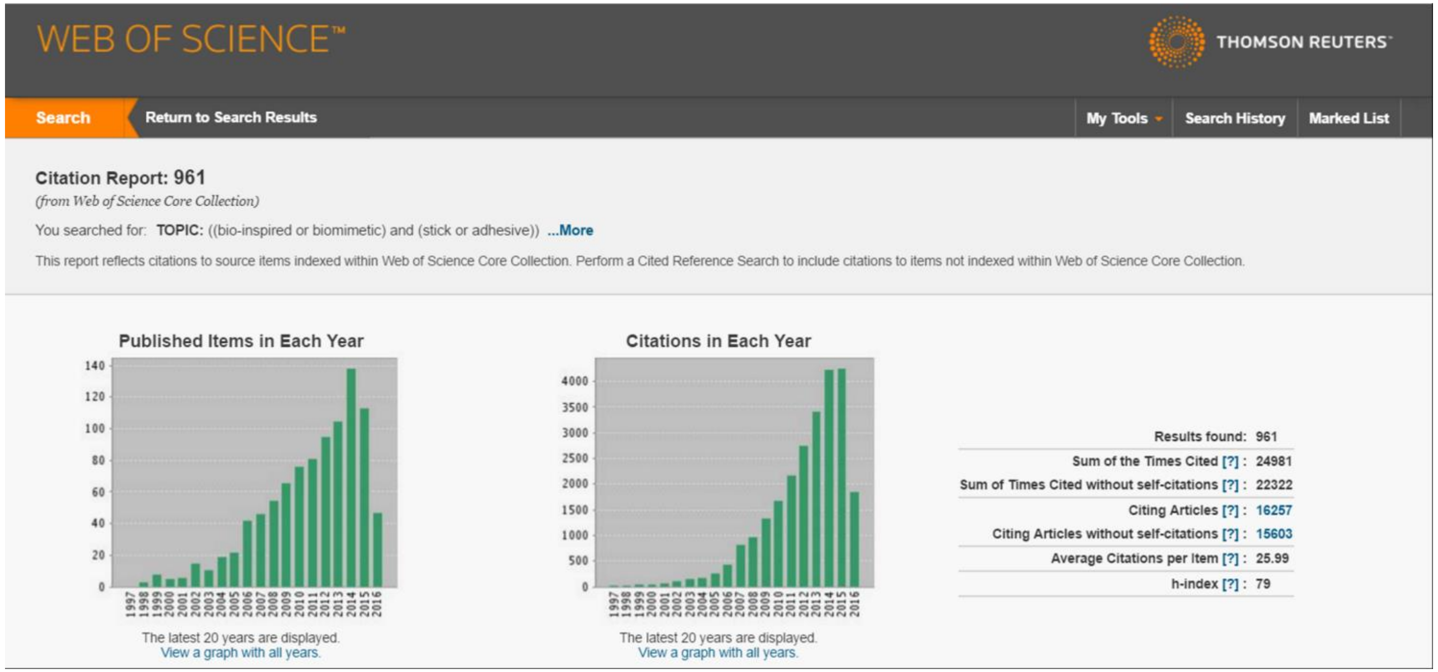

Badge et al. 2014

**Material Composition and Functions**

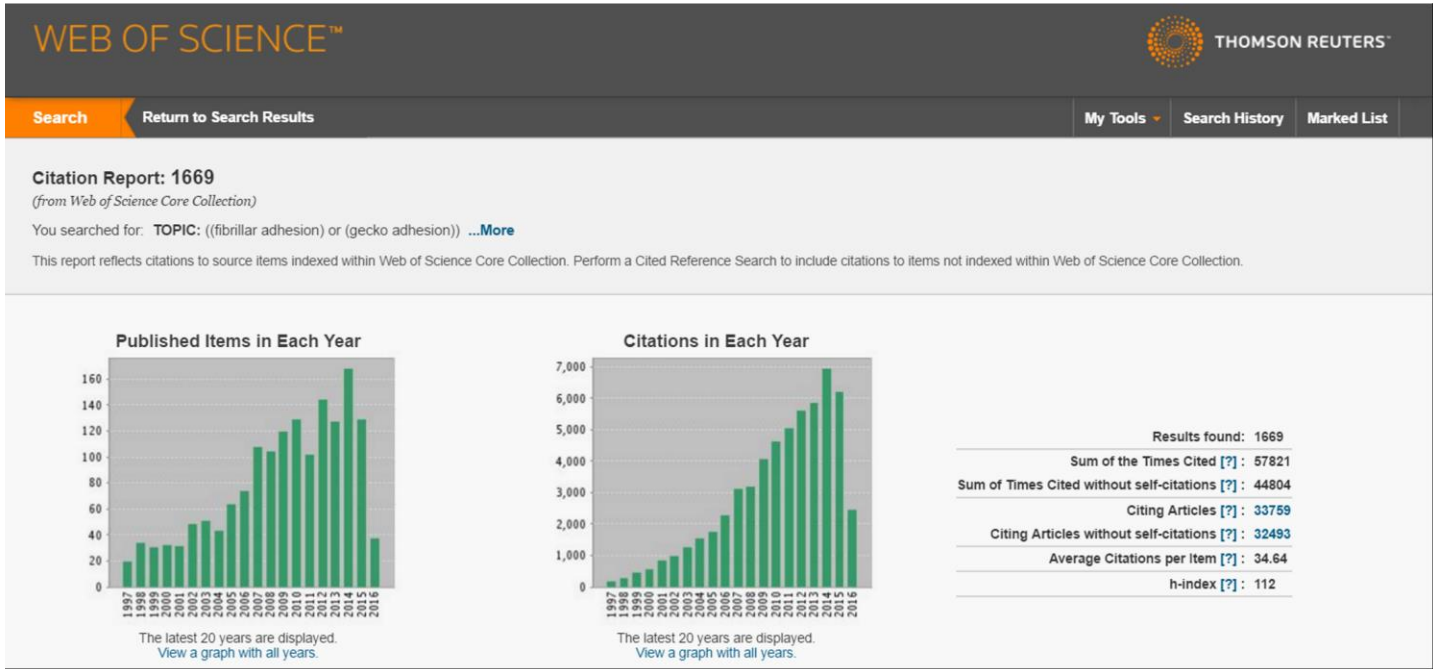


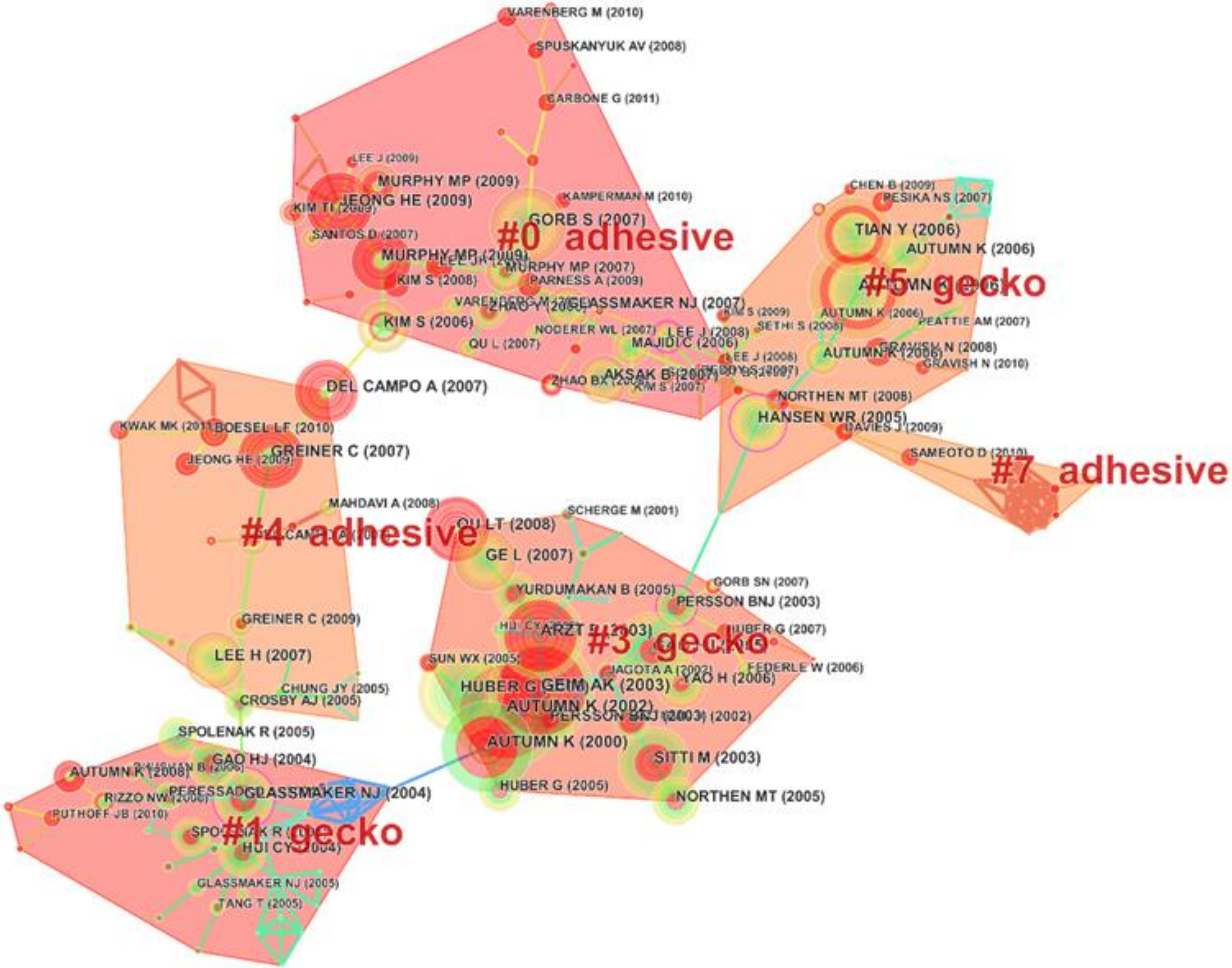

Jain et al. 2015

## Bioinspired Adhesive




## Fibrillar or Gecko Adhesive

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GORB S (2007)
#0 adhesive
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MURPHY MP (2007)
KIM S (2008)
PARNESS A (2009)
GLASSMAKER NJ (2007)
KIM S (2006)
NODERER WL (2007)
LEE J (2008)
QU L (2007)
MAJIDI C (2006)
AKSAK B (2007)
KIM S (2007)
DEL CAMPO A (2007)
CHEN B (2009)
PESIKA NS (2007)
TIAN Y (2006)
AUTUMN K (2006)
#5 gecko
KIM S (2009)
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SETHI S (2008)
PEATTIE AM (2007)
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HANSEN WR (2005)
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SAMEOTO D (2010)
#7 adhesive
BOESEL LF (2010)
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#4 adhesive
QU LT (2008)
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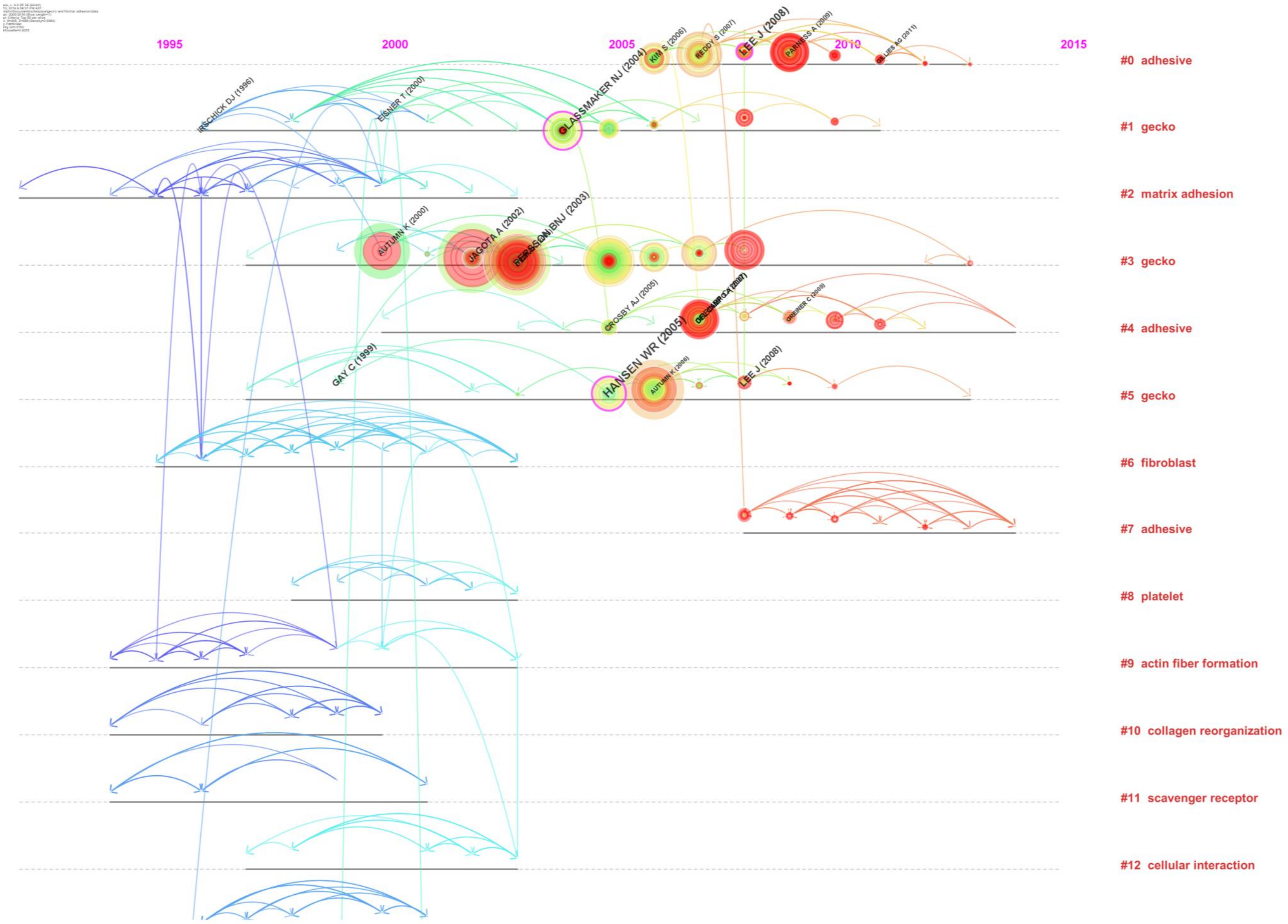
TANG T (2005)



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CROSBY AJ (2005)
GREINER C (2009)
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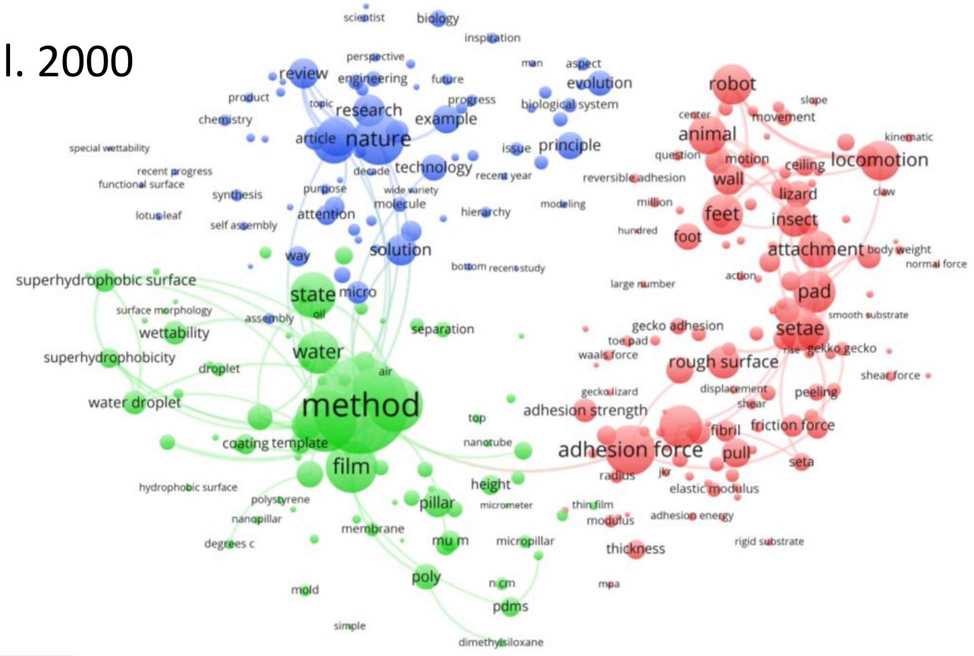
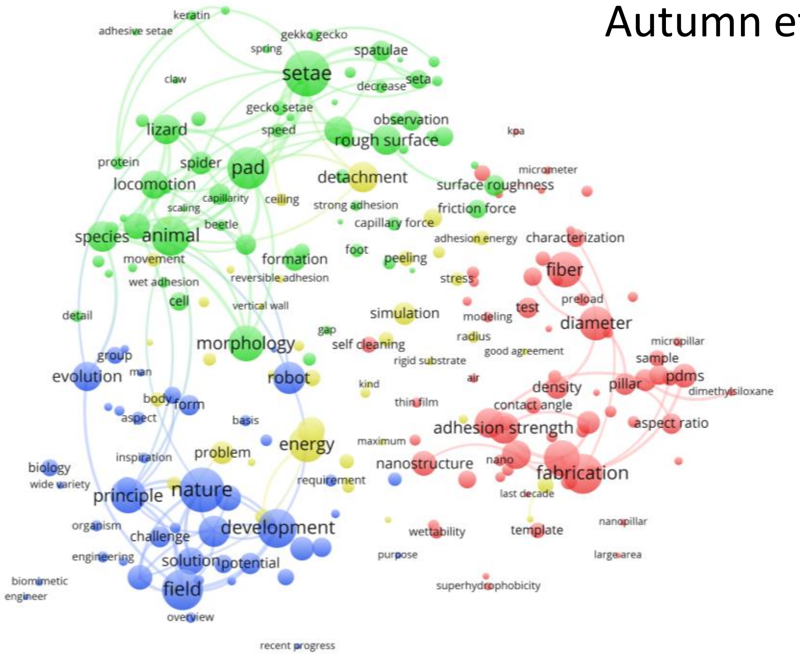
#0 adhesive
#1 gecko
#2 matrix adhesion
#3 gecko
#4 adhesive
#5 gecko
#6 fibroblast
#7 adhesive
#8 platelet
#9 actin fiber formation
#10 collagen reorganization
#11 scavenger receptor
#12 cellular interaction

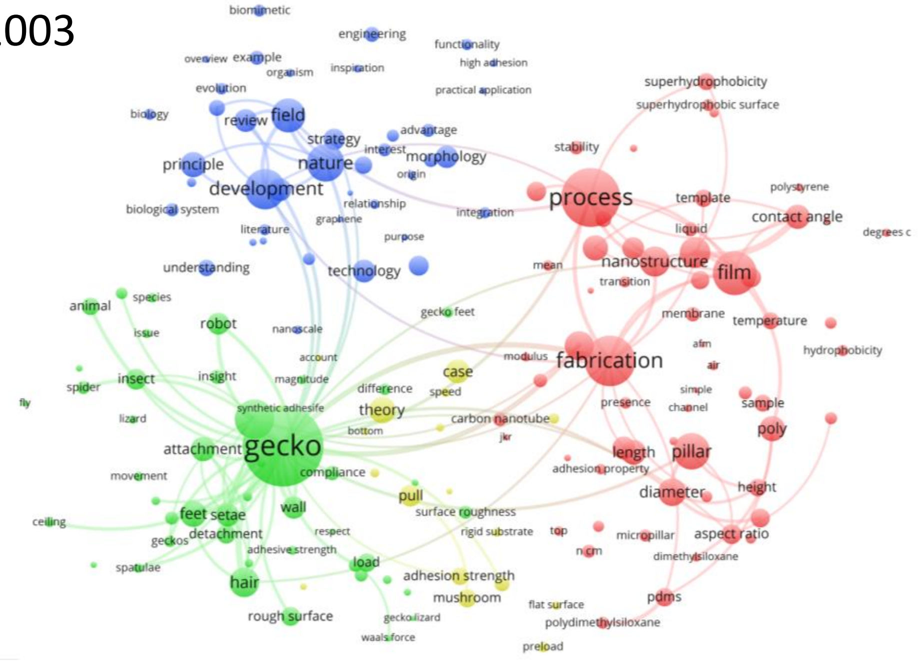
Autumn et al. 2000



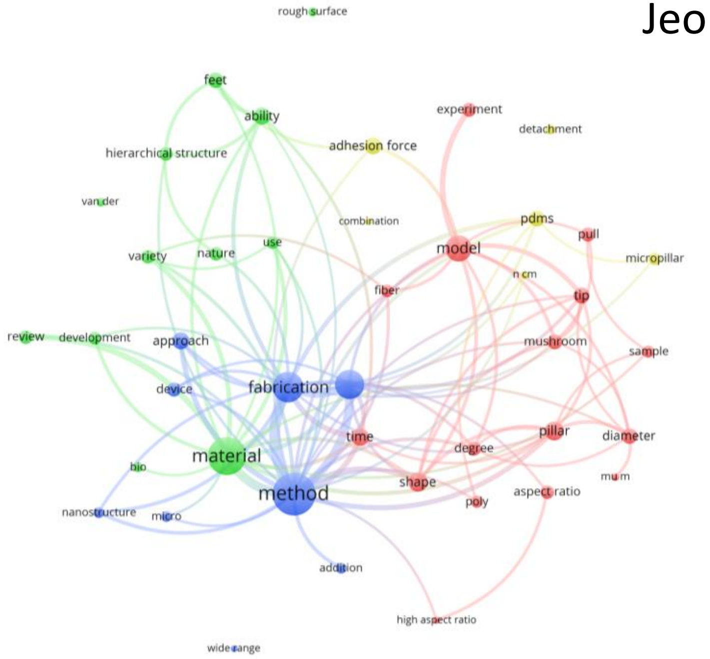

Autumn et al. 2002

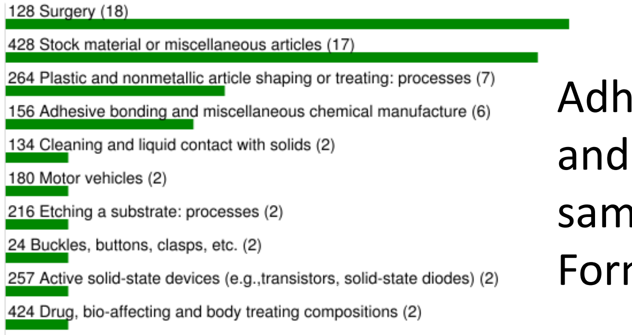



Geim et al. 2003

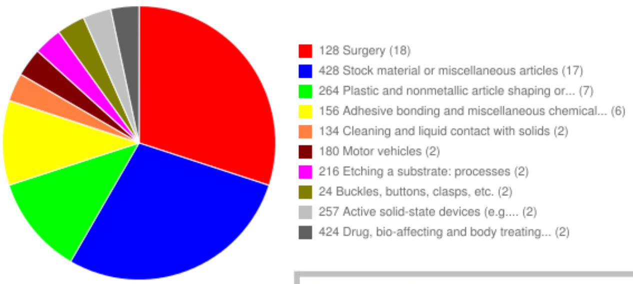


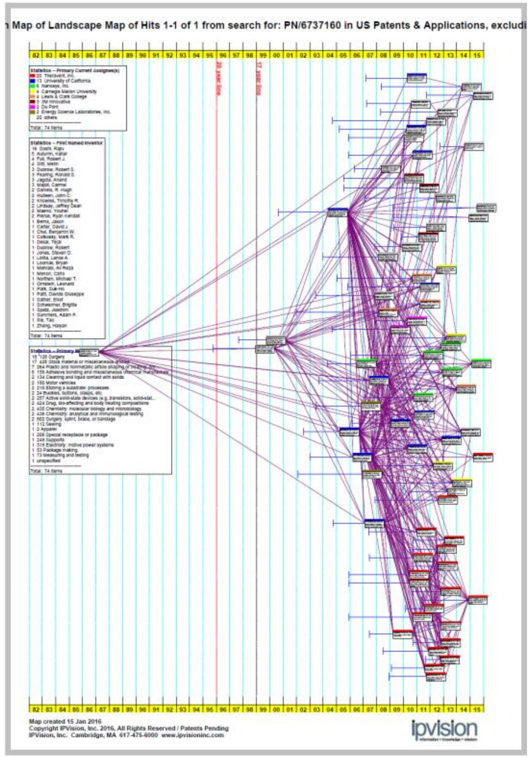

Jeong et al. 2009

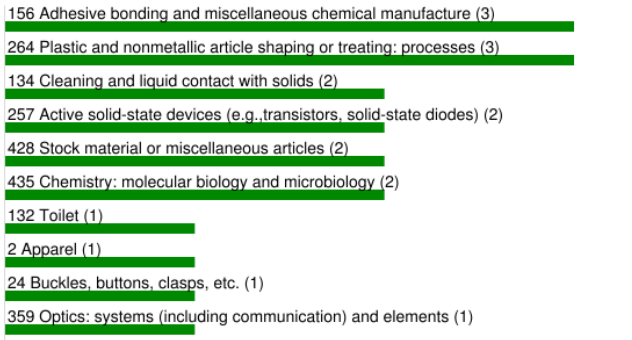




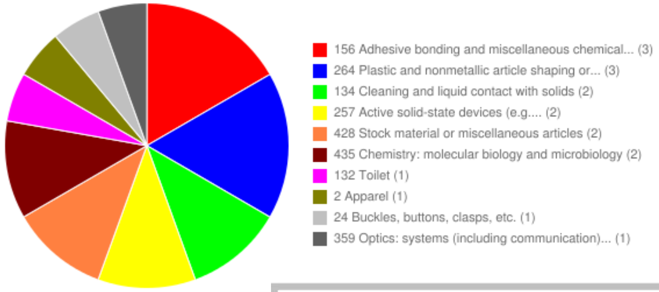

Adhesive microstructure and method of forming same US 6737160 Forming microstructure

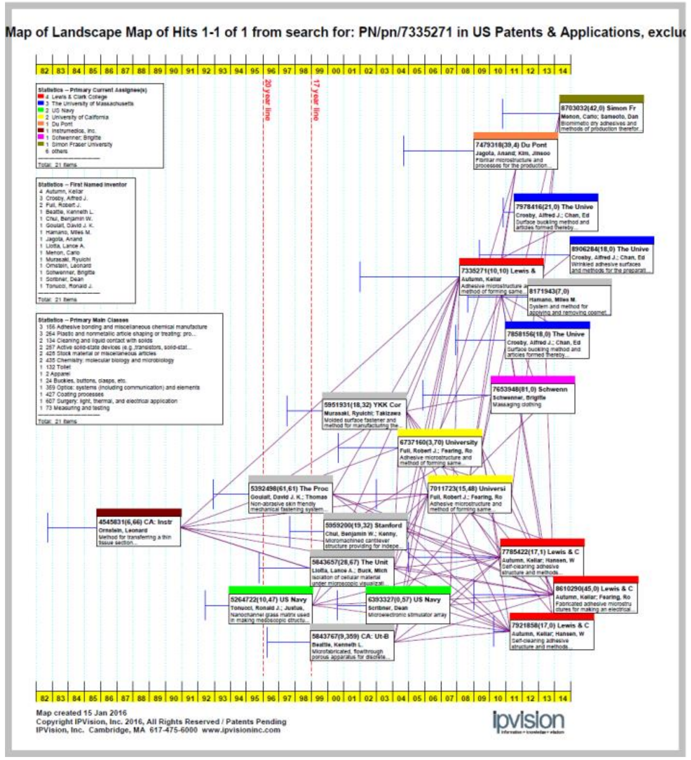


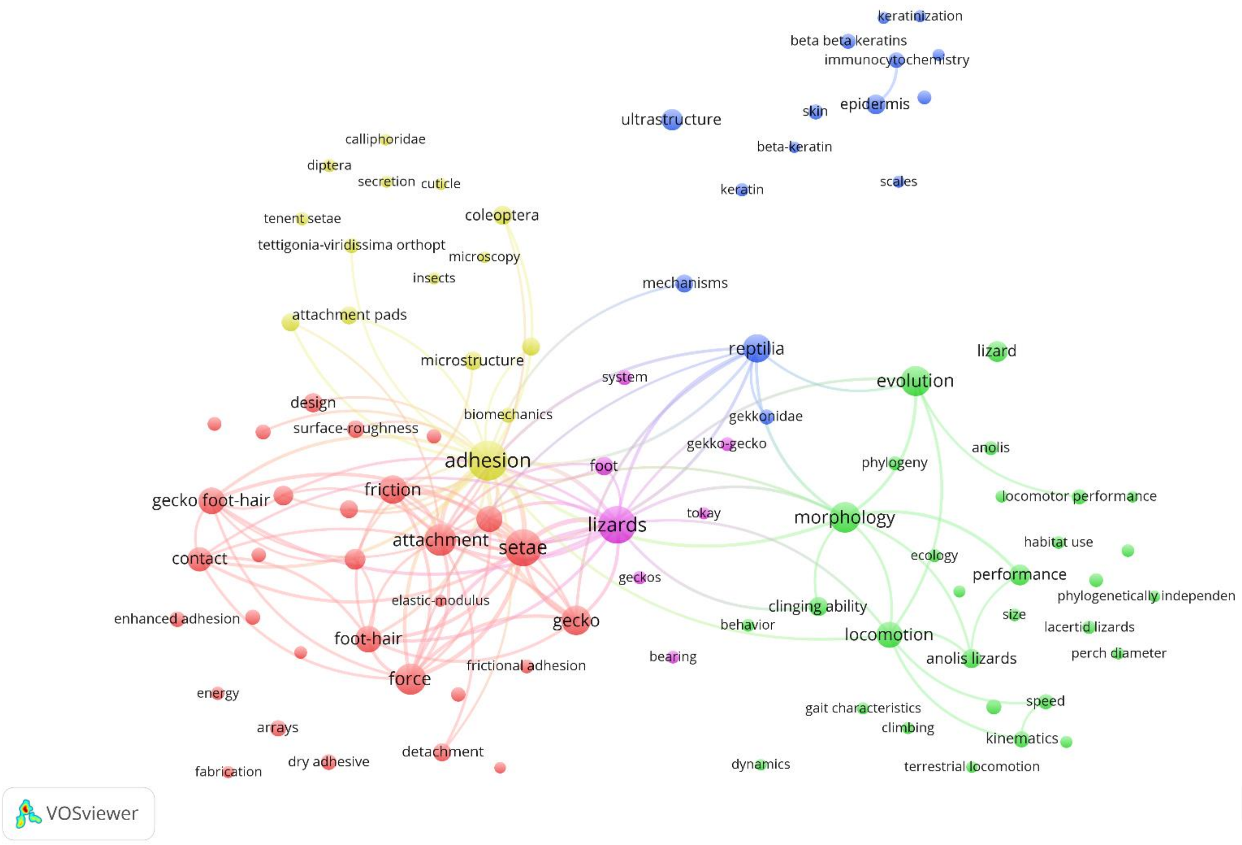




Adhesive microstructure and method of forming same US 7335271 Establishing adhesion

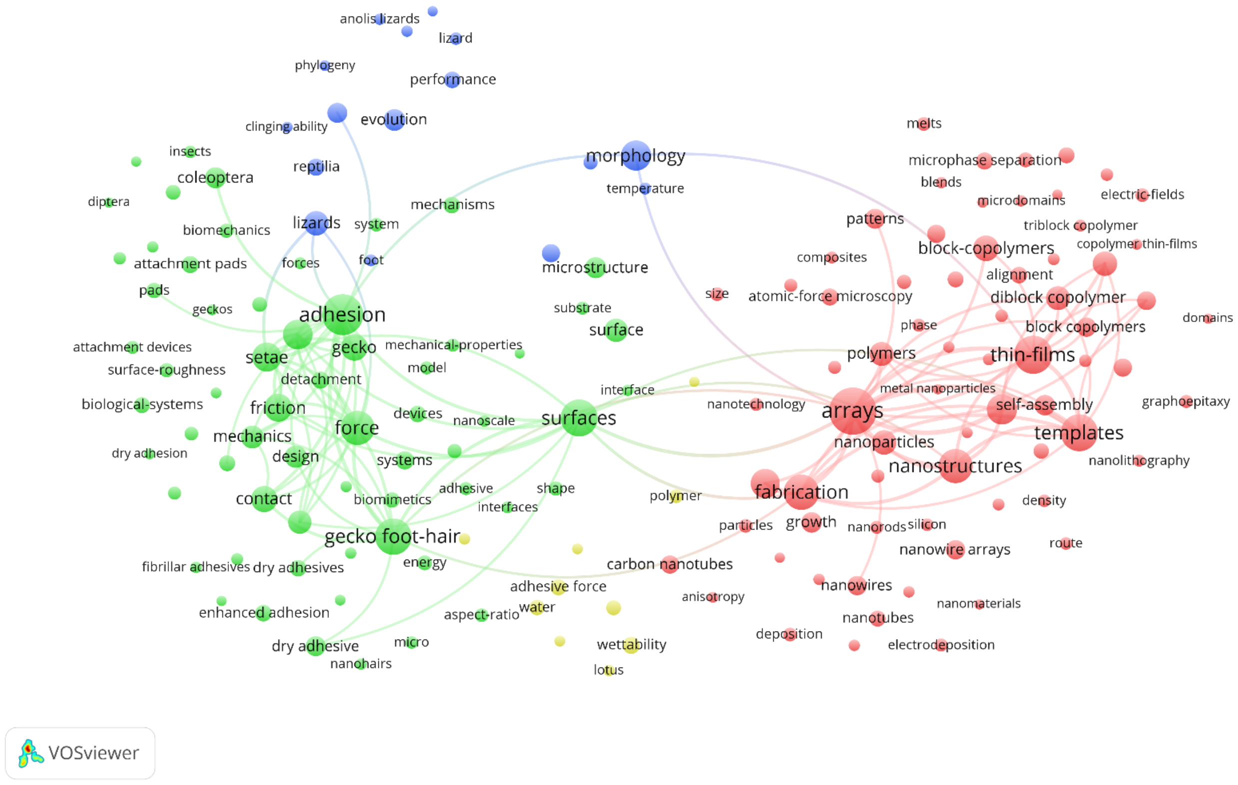


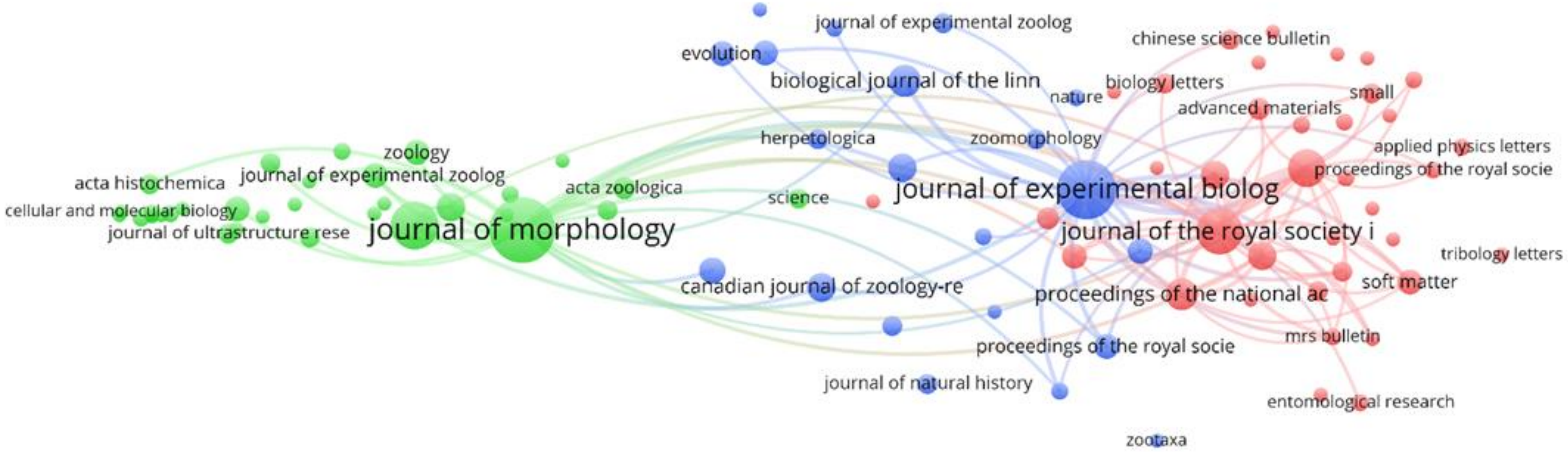



US 6737160
Forming microstructure




US 7335271
Establishing adhesion

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advanced materials
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zoomorphology
applied physics letters
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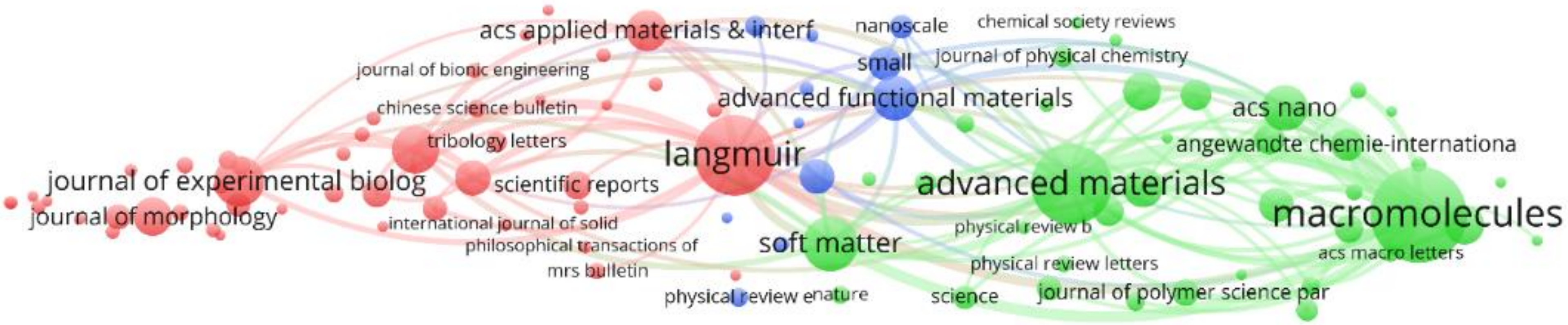
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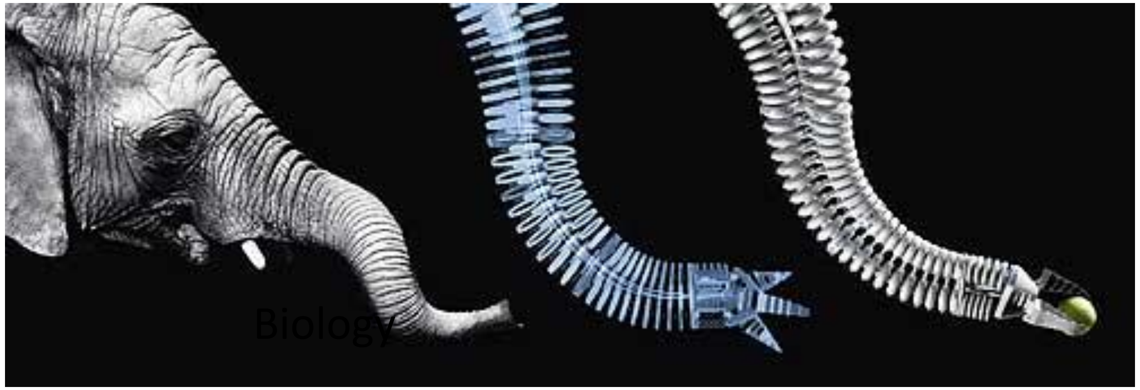
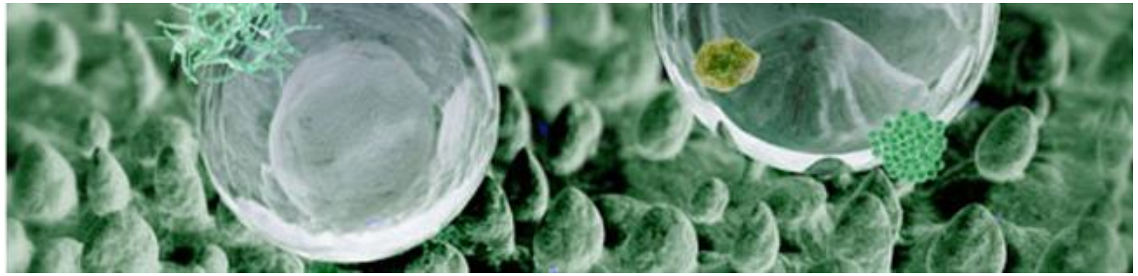
Biology

Business

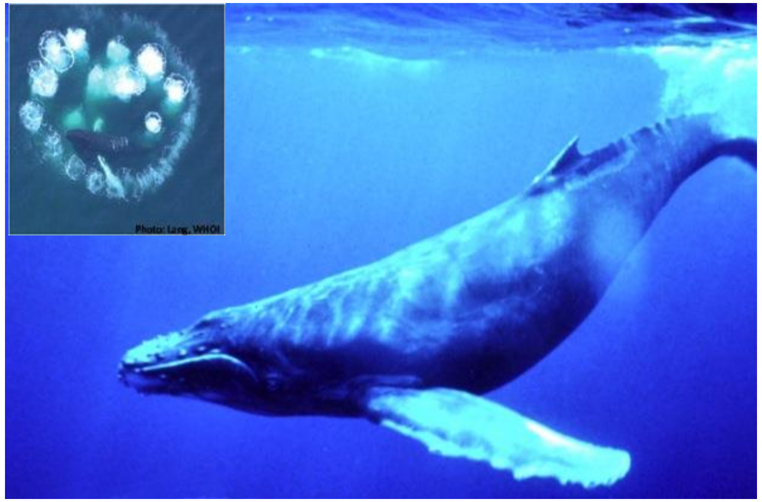


Engineering

Design

# 3.8 billion years of research



# Biomimetic vs. Human Engineered Solutions

Existing Solutions Databases (TRIZ structure)

Patents

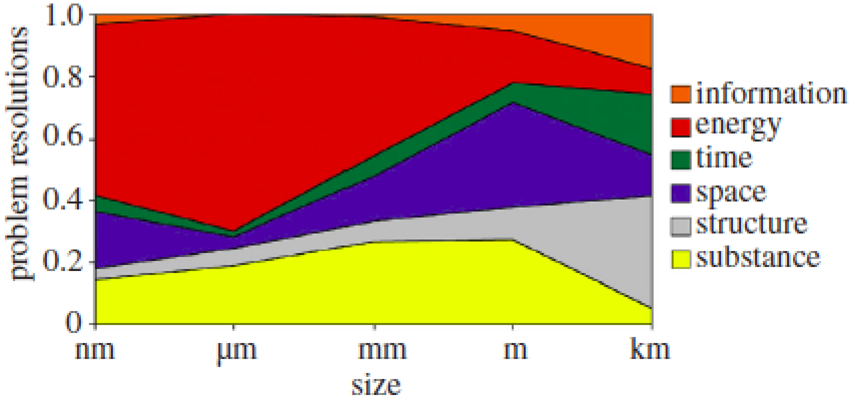



Figure 2. Engineering TRIZ solutions arranged according to size/hierarchy.

Biology

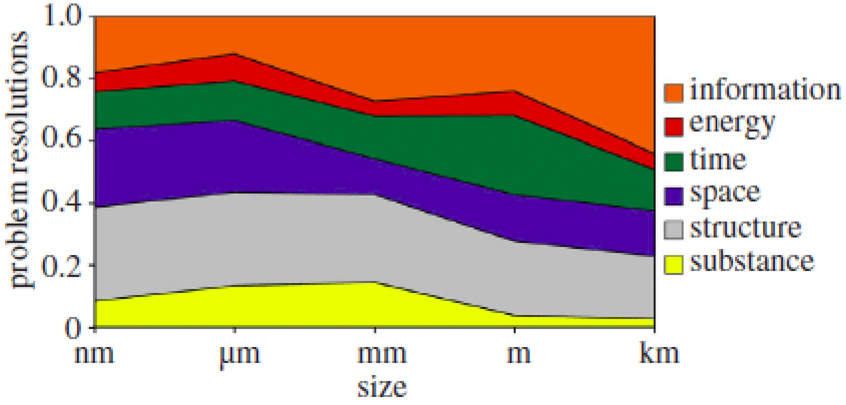
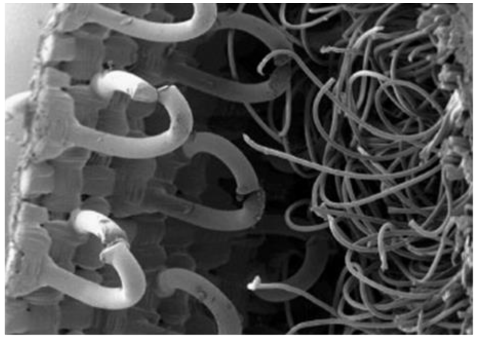


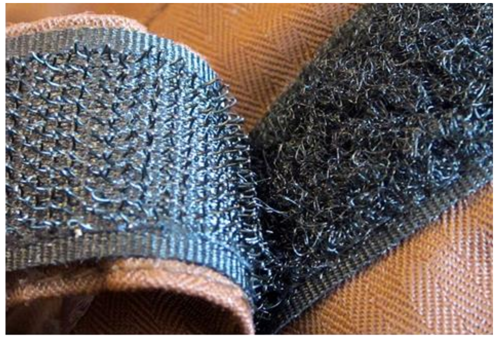

Figure 3. Biological effects arranged according to size/hierarchy.

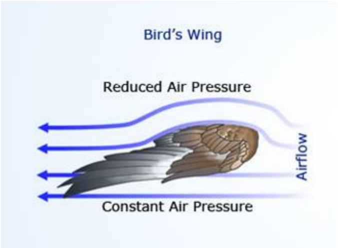
Vincent et al. 2006

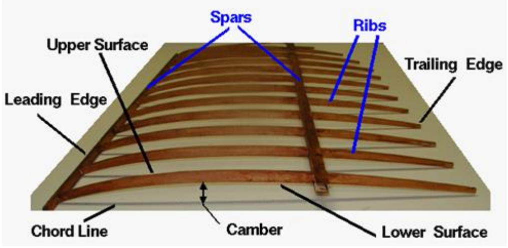
# Challenges and Limitations

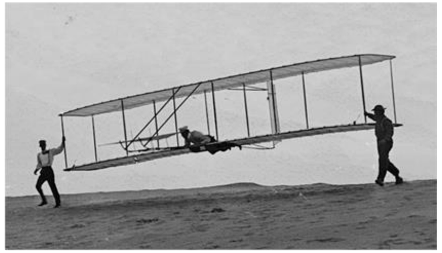
## Abstracting Biological Principles





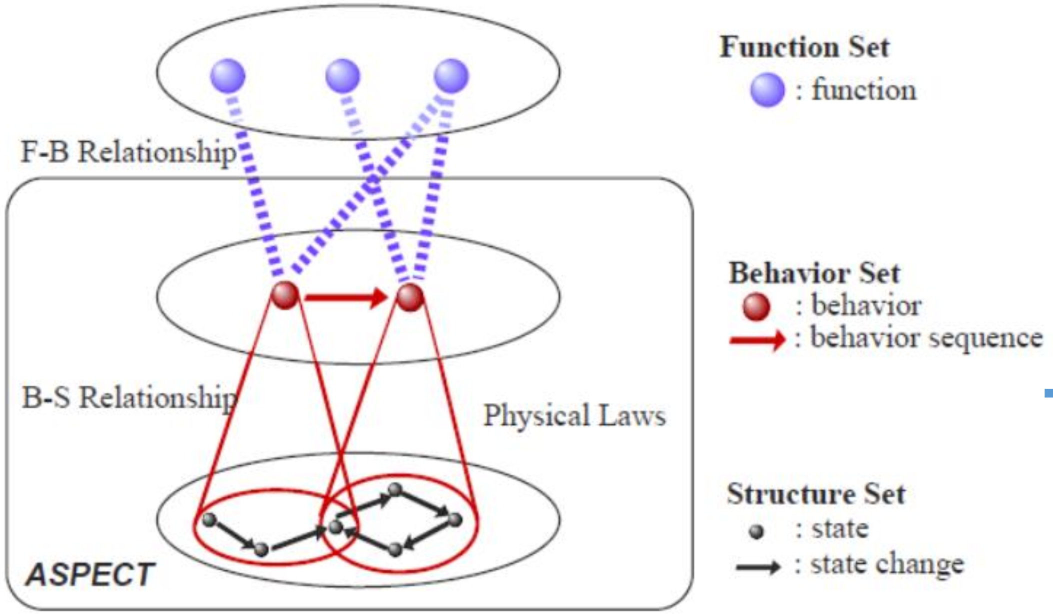


## Biology, Design, Tinkering and Engineering

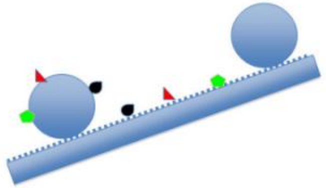
# **Challenges and Limitations:** Abstracting Biological Principles



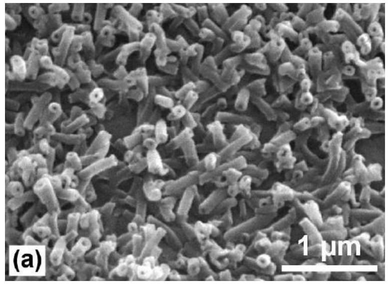

## SFB

Takeda et al. 1994

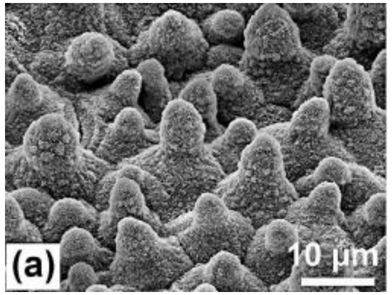
**Self-Cleaning**



**Hydrophobicity**




**Chemistry and morphology**



# **Challenges and Limitations:** Tinkering vs. Engineering/Design

10 June 1977, Volume 196, Number 4295

SCIENCE

## Evolution and Tinkering

François Jacob

Some of the 16th-century books devoted to zoology and botany are illustrated by superb drawings of the various animals that populate the earth. Certain contain detailed descriptions of such creatures as dogs with fish heads, men with chicken legs, or even women without heads. The notion of monsters that blend the characteristics of different species is not itself surprising: everyone has imagined or sketched such hybrids. What is disconcerting today is that in the 16th century these creatures belonged, not to the world of fantasies, but to the real world. Many people had seen them and described them in detail. The monsters walked alongside the familiar animals of everyday life. They were within the limits of the possible.

When looking at present-day science fiction books, one is struck by the same phenomenon: the abominable animals that hunt the poor astronaut lost on a distant planet are products of recombinations between the organisms living on the earth. The creatures coming from outer space to explore the earth are depicted in the likeness of man. You can watch them emerging from their unidentified flying objects (UFO's); they are vertebrates, mammals without any doubt, walking erect. The only variations concern body size and the number of eyes. Generally these creatures have larger skulls than humans, to suggest bigger brains, and sometimes one or two radioantennae on the head, to suggest very sophisticated sense organs. The surprising point here again is what is considered possible. It is the idea, more than a hundred years after Darwin, that, if life occurs anywhere, it is bound to produce animals not too different from the terrestrial ones; and above all to evolve something like man.

The interest in these monsters is that they show how a culture handles the possible and marks its limits. It is a requirement of the human brain to put order in the universe. It seems fair to say that all cultures have more or less succeeded in providing their members with a unified and coherent view of the world and of the forces that run it. One may disagree with the explanatory systems offered by myths or magic, but one cannot deny them unity and coherence. In fact, they are often charged with too much unity and coherence because of their capacity to explain anything by the same simple argument. Actually, despite their differences, whether mythic, magic, or scientific, all explanatory systems operate on a common principle. In the words of the physicist Jean Perrin, the heart of the problem is always "to explain the complicated visible by some simple invisible" (*1*). A thunderstorm can be viewed as a consequence of Zeus' anger or of a difference of potential between the clouds and the earth. A disease can be seen as the result of a spell cast on the patient or of an infection by a virus. In all cases, however, one watches the visible effect of some hidden cause related to the whole set of invisible forces that are supposed to run the world.

### The World View of Science

Whether mythic or scientific, the view of the world that man constructs is always largely a product of imagination. For the scientific process does not consist simply in observing, in collecting data, and in deducing from them a theory. One can watch an object for years and never produce any observation of scientific interest. To produce a valuable observation, one has first to have an idea of what to observe, a preconception of what is possible. Scientific advances often come from uncovering a hitherto unseen aspect of things as a result, not so much of using some new instrument, but rather of looking at objects from a different angle. This look is necessarily guided by a certain idea of what the so-called reality might be. It always involves a certain conception about the unknown, that is, about what lies beyond that which one has logical or experimental reasons to believe. In the words of Peter Medawar, scientific investigation begins by the "invention of a possible world or of a tiny fraction of that world" (*2*). So also begins mythical thought. But it stops there. Having constructed what it considers as the only possible world, it easily fits reality into its scheme. For scientific thought, instead, imagination is only a part of the game. At every step, it has to meet with experimentation and criticism. The best world is the one that exists and has proven to work already for a long time. Science attempts to confront the possible with the actual.

The price to be paid for this outlook, however, turned out to be high. It was, and is perhaps more than ever, renouncing a unified world view. This results from the very way science proceeds. Most other systems of explanation—mythic, magic, or religious—generally encompass everything. They apply to every domain. They answer any possible question. They account for the origin, the present, and the end of the universe. Science proceeds differently. It operates by detailed experimentation with nature and thus appears less ambitious, at least at first glance. It does not aim at reaching at once a complete and definitive explanation of the whole universe, its beginning, and its present form. Instead, it looks for partial and provisional answers about those phenomena that can be isolated and well defined. Actually, the beginning of modern science can be dated from the time when such general questions as, "How was the universe created?

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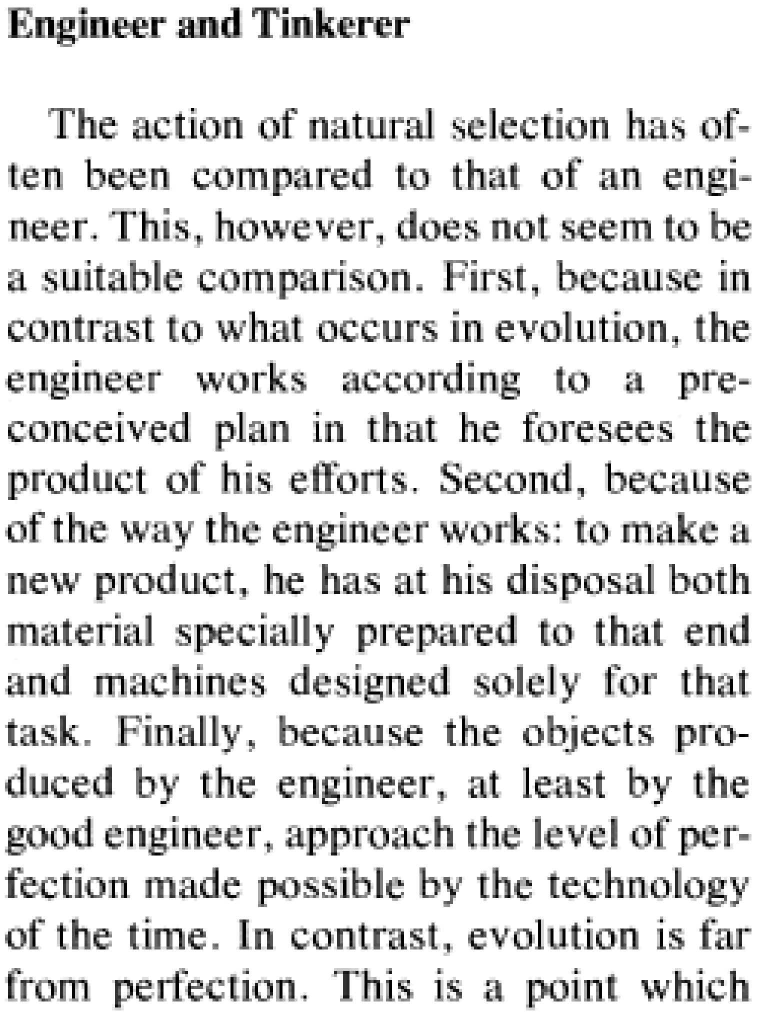


### Engineer and Tinkerer

The action of natural selection has often been compared to that of an engineer. This, however, does not seem to be a suitable comparison. First, because in contrast to what occurs in evolution, the engineer works according to a preconceived plan in that he foresees the product of his efforts. Second, because of the way the engineer works: to make a new product, he has at his disposal both material specially prepared to that end and machines designed solely for that task. Finally, because the objects produced by the engineer, at least by the good engineer, approach the level of perfection made possible by the technology of the time. In contrast, evolution is far from perfection. This is a point which

# Pattern and Process: Engineer vs. Tinker

**TABLE 1**

Summary of the Basic Features that Relate and Distinguish Different Types of Complex Networks, Both Natural and Artificial

| Property | Proteomics | Ecology | Language | Technology |
|---|---|---|---|---|
| Tinkering | Gene duplication and recruitation | Local assemblages from regional species pools and priority effects | Creation of words from already established ones | Reutilization of modules and components |
| Hubs | Cellular signaling genes (e.g., p53) | Omnivorous and most abundant species | Function words | Most used components |
| What can be optimized? | Communication speed and linking cost | Unclear | Communication speed with restrictions | Minimize development effort within constraints |
| Failures | Small phenotypic effect of random mutations | Loss of only a few species-specific functions | Maintenance of expression and communication | Loss of functionality |
| Attacks | Large alterations of cell-cycle and apoptosis (e.g., cancer) | Many coextinctions and loss of several ecosystems functions | Agrammatism (i.e., great difficulties for building complex sentences) | Avalanches of changes and large development costs |
| Redundancy and degeneracy | Redundant genes rapidly lost | R minimized and D restricted to non-keystone species | Great D | Certain degree of R but no D |

Here different characteristic features of complex nets, as well as their behavior under different sources of perturbation, are considered.

Sole et al 2003

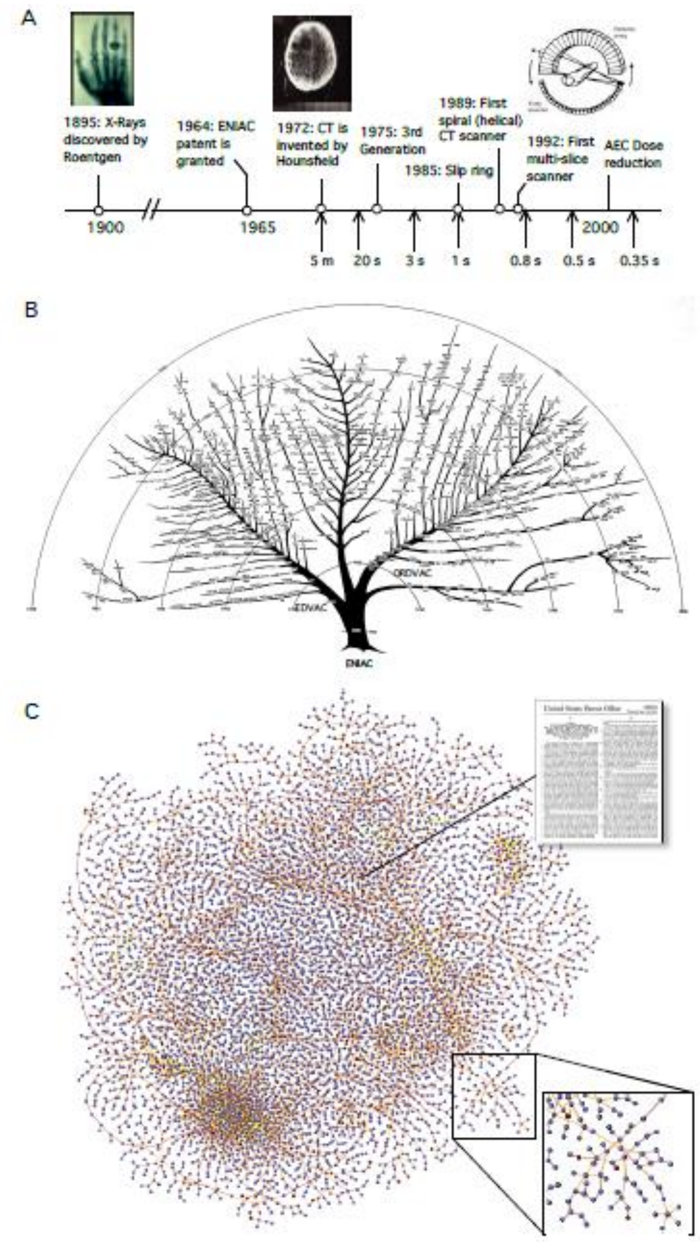
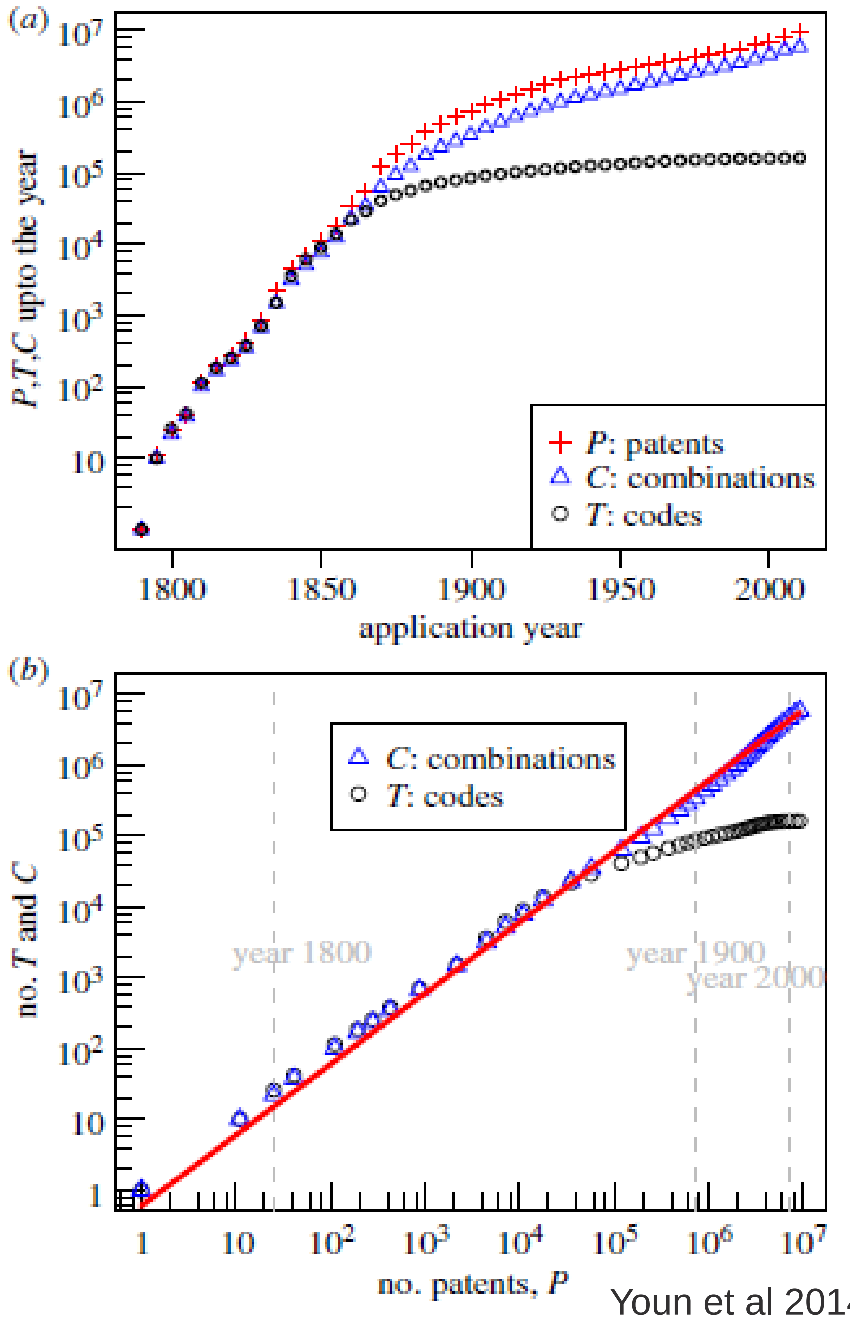



Fig. 1. Different representations of technological maps: (1) Technological timeline of computer tomography (1898-2000), (2) Phylogenetic tree of early computer hardware (1945-1970) and (3) Network of USPTO patent citations in the year 1963.

Valverde 2014




Youn et al 2014

# Reflections

- Repeatability and scalability
- What does adaptation mean
- Biomimetic solutions are not always better
- Biomimicry is an extraordinary platform for interdisciplinary collaboration

# Acknowledgments

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